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EXPLORATION GEOCHEMISTRY: THE LOS ALAMOS EXPERIENCE

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ABSTRACT

Los Alamos National Laboratory became actively involved in geochemical exploration in 1975 by conducting a reconnaissance-scale exploration program for uranium as part of the National Uranium Resource Evaluation program. Initially, only uranium and thorium were analyzed. By 1979 Los Alamos was analyzing a multielement suite. The data were presented in histograms and as black and white concentration plots for uranium and thorium only. Data for the remaining elements were presented as hard copy data listings in an appendix to the report.

In 1983 Los Alamos began using exploration geochemistry for the purpose of finding economic mineral deposits to help stimulate the economies of underdeveloped countries. Stream-sediment samples were collected on the Caribbean island of St. Lucia and a geochemical atlas of that island was produced. The data were statistically smoothed and presented as computer-generated color plots of each element of the multielement suite.

Studies for the U.S. Bureau of Land Management in 1984 consisted of development of techniques for the integration of several large data sets, which could then be used for computer-assisted mineral resource assessments. A supervised classification technique was developed which compares the attributes of grid cells containing mines or mineral occurrences with the attributes of unclassified cells not known to contain mines or occurrences. Color maps indicate how closely unclassified cells match in attributes the cells with mines or occurrences.

In 1986, Los Alamos conducted a geochemical exploration program in Costa Rica for the purpose of delineating areas with potential for mineralization. Major changes were made in methods of sample collection and data display. This program resulted in a significant expansion of the area known to have potential for gold mineralization in Costa Rica.

INTRODUCTION

Regional geochemical exploration programs have been conducted by Los Alamos National Laboratory (LANL) since the mid 1970s. The settings have ranged from permafrost areas in Alaska, to arid regions of the southwestern United States, to subtropical areas of Central America and the Caribbean region. Techniques for sample collection, analysis, and data display have improved as LANL gained experience. This paper is an overview of some of the geochemical exploration programs conducted by Los Alamos.

THE NATIONAL URANIUM RESOURCE EVALUATION PROGRAM

Los Alamos National Laboratory became actively involved in exploration geochemistry in 1975 when the US Atomic Energy Commission (now the Department of Energy) asked LANL to design and manage a hydrogeochemical survey of surface and ground waters and water-deposited sediments as part of the National Uranium Resource Evaluation (NURE) program. Los Alamos' area of responsibility was the Rocky Mountain states of New Mexico, Colorado, Wyoming, and Montana, and the state of Alaska. The total area of the five states is approximately 2.7 million km^2. The information provided by the Hydrogeochemical and Stream Sediment Reconnaissance (HSSR), in conjunction with that produced by other NURE programs, made it possible to estimate more accurately the nation's long-range uranium resources and also identify promising areas for future exploration.

The LANL program was designed upon the results of similar surveys conducted in many parts of the world during the previous 30 years, and orientation studies conducted by LANL. Water and water borne sediment samples were collected at an average density of one per 10 km^2 throughout each of the Rocky Mountain states and in mountainous regions of Alaska. Whenever possible, both water and sediment were collected at each location. In areas of Alaska extensively covered by lakes, lake water and bottom sediment were collected from one location every 23 km^2.

All samples were processed in the field according to stringent standards established by LANL. Water samples were filtered to remove particulates (except in Alaska) and acidified to keep the elements in solution. The sediment was dried and then sieved through 100 mesh (150 micron) sieves.

Initially, samples were analyzed only for uranium and thorium. Beginning in late 1977, the scope of the HSSR was broadened considerably to include a multielement suite. Water samples were analyzed for uranium by fluorometry which had a 0.02 parts per billion lower limit of detection. Concentrations of 12 additional elements in water were determined by plasma-source emission spectrography. All sediments were analyzed for uranium by delayed-neutron counting. Elemental concentrations in sediments were also determined by neutron activation analysis for 31 elements, by x-ray fluorescence for 9 elements, and by arc-source emission spectrography for 2 elements.

The data were reported by National Topographic Map Series quadrangle boundaries (1 degree latitude x 2 degrees longitude), scale 1:250,000. A typical quadrangle has 1500 to 2000 sample locations and covers 15,000 to 20,000 km^2, depending on latitude. The data are presented in formal reports with brief sections on climate, geography, hydrology, and known uranium occurrences. The uranium data are briefly discussed; however, multielement data are included only in the appendices. The information resulting from the HSSR is available to the public as open-file reports.

Each report contains a suite of standard histograms of uranium concentrations for each sample type (stream waters, stream sediments, etc.). These histograms are used both to evaluate the data and to establish reasonable limits in selecting intervals for the various concentration overlays, which are also included with each report. The concentration overlays are at 1:250,000 scale to be used in conjunction with the appropriate 1:250,000-scale geologic and topographic maps. Geologic maps, when not already available at this scale, were compiled and included with the reports. Overlays, for sample locations, uranium concentrations in waters, conductivities in waters, uranium concentrations in sediments, and thorium concentrations in sediments, are included in the report. Appendices include listings of field data and elemental concentrations for both waters and sediments, and a summary of standard LANL HSSR procedures and codes.

CARIBBEAN INITIATIVE - ST. LUCIA, WEST INDIES

In 1983 Los Alamos National Laboratory conducted a geochemical survey on the island of St. Lucia for the purpose of assessing that country's mineral resource potential. This study was financed and supported by the Government of St. Lucia, the Caribbean Development Bank, the United States Agency for International Development, and Los Alamos National Laboratory.

St. Lucia is a tropical island some 40 km long and up to 20 km wide, covering an area of about 620 km^2. It is part of the Lesser Antilles island-arc chain on the eastern edge of the Caribbean plate. The island is comprised of Tertiary through Quaternary age volcanic rocks. The oldest rocks are the 18 m.y. old basalts in the extreme northern portion of the country (Briden et al., 1979). The volcanics generally become progressively younger southwards and range in composition from basalts in the north, to andesites in the central region, to dacites in the south (Newman, 1965).

A total of 307 stream-sediment samples was collected at a nominal density of one sample per 2 km^2. Fifty-five beach-sand samples were also collected. All samples were analyzed for 51 elements by instrumental neutron activation. The sampling program was largely patterned after other successful geochemical surveys conducted by Los Alamos (Bolivar, 1981; Earth and Space Sciences Division, 1984). For stream sites, a composite sample of fine-grained material was collected from three adjacent spots in the active stream bed. About one kilogram of sediment was collected from every site to ensure that at least 25 g of usable sediment would be left after the sample was dried and sieved to minus 100 mesh (150 microns). Beach sands were collected above high tide level and were not sieved. Samples were analyzed at Los Alamos for 51 elements by delayed-neutron counting, instrumental neutron-activation analysis, and x-ray fluorescence.

Stream-sediment samples were collected at irregular intervals due to geography, access, etc. To make the analyses amenable to visual projections, the data were interpolated to a grid. Based on sample density, a grid cell resolution of 1 km^2 was selected. This resulted in a 35 x 50 grid, or 1750 cells. Universal Kriging was used to interpolate the data to each grid cell plotted on a Universal Transverse Mercator projection.

Color plates were used to display regional geochemical characteristics of the stream-sediment data. The use of color images enables the geologist to rapidly visualize broad geochemical trends, place local geochemical patterns within the regional framework, and to observe correlations among the elements presented. Beach-sand samples were too irregularly distributed to be amenable to color projections; consequently, only black and white concentration plots and basic statistics were used in interpretation.

Two types of visual displays were used to project the geochemical data: a color-contour image, which shows the spatial and statistical distribution for each element; and a three-element image, which projects the spatial correlations for three elements simultaneously. A color-contour image projects an elemental concentration in each grid cell as a color, whereas a three-element image projects each element in a different primary color (red, green, or blue) simultaneously. When all three are projected simultaneously, new colors are created by the rules of color addition. For example, red and blue correlations are displayed as shades of magenta, and green and blue correlations are displayed as shades of blue-green. If all three elements have concentrations in the same percentile ranking with respect to their individual populations, a shade of gray or white is generated.

An "anomaly threshold" was subjectively chosen to delineate samples with concentrations higher than background levels. The median values were determined to be the best guides to background. Anomaly thresholds were assigned based upon the histograms and published data for the average contents of each element for individual rock types.

The element with the greatest chance for development, and with a reasonable chance of being found in St. Lucia's geological environment, is gold. Therefore, although the data indicate several areas with some chance for other types of mineralization, only those that indicate the presence of gold mineralization are emphasized.

The two most significant gold anomalies on St. Lucia are located within the Roseau River and Ravine Souffre drainage areas. Although the stream sediments themselves do not contain enough gold to be an economic source of the metal, there are several indications of a possible vein system within the volcanic terrane. Samples from the Roseau River drainage area contain some of the highest gold concentrations found (0.07 ppm), as well as anomalous concentrations of arsenic, antimony, and selenium, all of which are known pathfinders for hydrothermal gold deposits. Samples from the Ravine Souffre anomaly near Marc Marc are characterized by lower gold concentrations, but contain anomalous concentrations of several pathfinder elements. In addition, samples from both the Roseau River and Ravine Souffre anomalies contain higher than average tin and base metal concentrations (copper, nickel,lead), which is another favorable indication of mineralization. Lastly, both of these anomalies lie within arcuate-shaped depressions that may be collapse calderas. If so, faults and fractures associated with these calderas would provide convenient conduits for hydrothermal solutions. Consequently, these two areas have several favorable indications of mineralization and should be the primary targets for future detailed studies.

The beach-sand data reveals no economic concentrations of the elements that might be expected to accumulate in beach placer deposits. Instead, the beach sand geochemistry generally reflects the onshore geology.

A COMPUTER-ASSISTED MINERAL RESOURCE ASSESSMENT OF SOCORRO AND CATRON COUNTIES, NEW MEXICO

In 1984, at the request of the U.S. Bureau of Land Management, staff of the Geology-Geochemistry Group of the Los Alamos National Laboratory conducted a computer-assisted resource assessment of Catron and Socorro counties, New Mexico. Objectives of this work included demonstration of the utility of computer-assisted resource assessments, development of new techniques and software to perform such assessments, and transferral of the techniques and software to the Bureau of Land Management for use in other areas.

To accomplish the assessment the following digital data sets were utilized: (1) NURE HSSR Geochemical, (2) aeromagnetic, (3) digital gravity, (4) digital topography, (5) Central Resource Information Bank (CRIB), (6) Minerals Availability System Non-Confidential (MAS-NC), and (7) Mineral Industry Location (MILS). These data sets were computer plotted on a 1-km grid covering the two counties. An updated geologic map was compiled using recent maps, theses, dissertations, and reports of federal and state agencies. This map was digitized using the 1-km grid system. Locations of mineral deposits and occurrences were compiled from all accessible sources and entered into the computer data base.

After correction for analytical differences between the two laboratories performing the analyses, geochemical results were displayed as computer-generated color plates. Bouguer gravity and aeromagnetic values are also provided as color plates. A new geologic map was compiled, digitized, and converted to a set of overlays, which permit a comparison of surficial geology with geochemical anomalies. A new technique was developed to utilize the Bouguer gravity and aeromagnetic data for structural interpretations. These results supplement the structural data obtained from the geologic map compilation. A trend-surface technique was also developed to remove the influence of rock type from raw geochemical data. The resulting residual geochemical values should more accurately reflect mineralization.

Two land classification techniques were utilized for this project. The first, a supervised classification, is based upon comparison of the attributes of grid cells containing mines or mineral occurrences with the attributes of unclassified cells not known to contain mines or occurrences. Attributes include the values of all digitized data sets. Color maps indicate how closely unclassified cells match in attributes the cells with mines or occurrences. A second, simpler classification uses residuals of bedrock trend surface analysis. Cells with the highest values of residuals are considered to have the highest potential for a given metal.

The results of the two classifications are presented in tabular form indicating areas that have the highest potential for a given commodity. For all metals examined a number of high-potential areas are identified in addition to known mineral occurrences. Land utilization planning can be significantly improved by comparing the location of these high-potential areas with the overlay showing lands administered by the U.S. Bureau of Land management. The new techniques utilized in this study allows any region with available NURE HSSR data to be evaluated for mineral potential. Even where geophysical data are not available, the classification based on residual geochemical values is valuable for predicting resource potential.

GEOCHEMICAL EXPLORATION IN COSTA RICA

The Geochemical Atlas of the San Jose and Golfito quadrangles, Costa Rica, was the first of a series of compilations of 1:200,000-scale maps of elemental concentrations in stream-sediment samples. It was produced through the cooperative efforts of Los Alamos National Laboratory, the Ministerio de Industria, Energia y Minas of Costa Rica, Direccion de Geologia, Minas e Hidrocarburos (MIEM), and the Escuela Centroamericana de Geologia, Universidad de Costa Rica (UCR) as part of the Mineral Resource Assessment of Costa Rica. This assessment of Costa Rica also includes a Preliminary Mineral Resource Assessment and a detailed study of the gold district in the Tilaran-Montes del Aguacate Range by the U.S. Geological Survey (USGS), MIEM, and the UCR (USGS and others, 1987).

The primary objective of the Mineral Resource Assessment was to stimulate the growth of the mining industry in Costa Rica by providing geochemical maps and geological data that can be used to identify areas favorable for the exploration of metallic mineral resources. A secondary objective was to train Costa Rica's geologists and geology students from the UCR. One student completed all the requirements for his M.S. thesis; much of the methodology of our stream-sediment survey was based on this thesis (Arauz, 1986). In addition, a five-week field-oriented training session involved thirteen students and four professors from the UCR.

The Atlas contains a description of data processing procedures, selected geochemical maps and overlays for the San Jose and the Golfito quadrangles, and all geochemical data on microfiche. Most of the mineral resources data of the San Jose and Golfito quadrangles are now available in three publications (Arauz, 1986; USGS and others, 1987; LANL and others, 1987). This information will provide the government and industries of Costa Rica with the technical data necessary to decide if future exploration activities in these quadrangles is feasible.

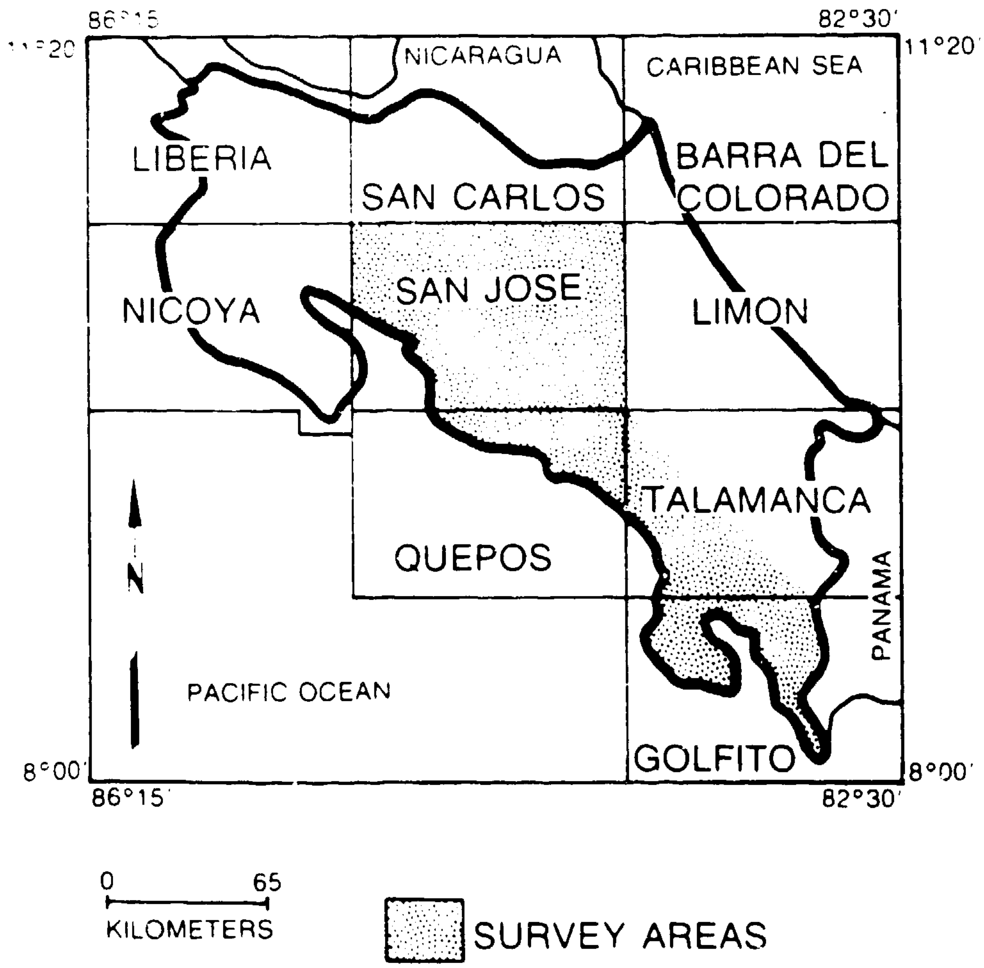

Figure 1. The 1:200,000-scale quadrangles sampled, between January and April 1986, as part of the stream-sediment geochemical reconnaissance survey.

Selection of Survey Areas

The San Jose and Golfito 1:200,000-scale quadrangles (Fig. 1) were selected as survey areas by joint agreement between Los Alamos, USGS, MIEM, and UCR personnel on the basis of known and potential mineral deposits. The San Jose quadrangle contains several gold mines within the Tilaran-Montes del Aguacate Range of Costa Rica. The Cordillera de Talamanca portions of these quadrangles may contain a northern extension of a porphyry copper province of Panama. These two areas are therefore representative of metallogenic provinces typical of Costa Rican mineralization.

Orientation Study, Sample Collection and Analysis

An orientation study was conducted in two areas of Costa Rica (Arauz, 1986). One area, located near Esparza, includes a portion of the gold district in the Tilaran-Montes del Aguacate Range and contains the Santa Clara gold mine. This is currently the largest gold mine in Costa Rica and it occurs in volcanic deposits. The other area is located within the Talamanca quadrangle, near San Isidro, and contains a major copper prospect. The geology here includes intrusive and volcanic sequences. The two study areas covered a total of about 200 km^2.

The orientation study compared wet and dry sieving techniques, examined the effects of analyzing different sieve-size fractions, and evaluated various sampling densities. The results of this study led to the selection of the wet-sieving technique, a sieve-size of minus 80 mesh, and a sampling density of one sample per 15-20 km^2. Sample site selection generally began at the headwaters of each major drainage. Drainage basin boundaries were drawn on 1:50,000-scale topographic maps and sample sites were selected based upon both a visual estimation of a 15-20 km^2 drainage basin size and perceived difficulty in access. Detailed descriptions of the sampling techniques can be found in Arauz (1986) and Bolivar (1987).

After collection, samples were dried and divided into three splits. One split of each sample was retained in Costa Rica by MIEM and the other two were returned to Los Alamos for analysis. Forty-six elements were determined by instrumental neutron activation analysis, and lead, silver, mercury, and copper were determined by atomic absorption. Loss on ignition was also determined. Details of the neutron activation analytical techniques are given in Garcia and others (1982), Maassen and others (1984), and Minor and others (1981).

Data Processing

Information, in the form of maps, chemical analyses, etc., must be put into a form that a computer can retrieve and process. This procedure is called digitization and simply represents information as a number. A computer can then quickly and efficiently manipulate these numbers.

Digital data types that have been compiled for the Atlas are listed in Table I. Some of this information, such as bedrock and float percentages, river gradients, and contamination factors, may only be of use for more sophisticated multivariant statistical analysis techniques (Davis, 1986). For example, mine locations, when combined with basin outlines and geochemical analyses, provide a basis for discriminant or supervised classification analysis.

TABLE I. TYPES OF DIGITAL DATA

Data Type	Source	Method of Input	Graphic Type
Bedrock	USGS and others, 1987	Digitizer	Polygons with rock type label
Mineral Occurrences	USGS and others, 1987	Keypunch	Point
Culture/Landmarks	1:200,000 and 1:50,000 topographic map series of Costa Rica	Digitizer	Polygons with labels, lines
Geochemistry	Analysis of stream-sediment samples	Magnetic tape	Values converted to color indices
Geology:			
Float percentages	Field observation	Keypunch	--
Bedrock percentages	Joint usage of basin outlines and 1:200.000-scale bedrock data	Interactive computer graphics	--
Basin outline	1:50,000 topographic map series of Costa Rica	Digitizer	Polygons with labels
Basin area	Basin outlines	Software	--
Rivers containing sample sites	1:50,000 topographic map series of Costa Rica	Digitizer	Lines with labels identifying interconnected sample sites
Sample site elevations	1:50,000 topographic map series of Costa Rica	Keypunch	--
River gradients in basins	Joint usage of river and elevation data	Software	--
Dilution factor:			
Relative discharge of rivers entering basin	Joint usage of river and basin area data	Software	--
Relative incremental contribution to discharge from drainage basins	Basin area data	Software	--
Contamination factor:			
Percentage of basin identified as townsites	Joint usage of basin outlines and 1:50,000 cultural data	Interactive computer graphics	--

Stream-sediment samples are comprised of materials weathered from rocks that crop out within and upstream of the drainage basin represented by the sample. By representing geochemical concentrations within drainage basin boundaries it is possible to delineate areas of geological interest within the specific boundaries defined by the drainage basin. The use of drainage basins also facilitates the study of geochemical dispersion trains, which can be used to identify possible areas of mineralization (Levinson, 1980). Consequently, the basic unit for data display is the nominal 15-20 km^2 drainage basin. The geochemical analyses reflect not only the geochemistry of the area contained within each drainage basin, but also influx of material upstream for the entire catchment basin.

The geochemical data for each drainage basin are color coded to represent the elemental concentration within the drainage basin immediately above each sample site. High elemental concentrations are shown in warm colors (for example, red), whereas low concentrations are in shades of cool colors (for example, blue). Geochemical analyses shown in color-coded maps provide a method for rapidly examining and interpreting voluminous data sets. The drainage basin outlines and stream drainages are included on each map to facilitate interpretation.

Use of the Atlas

Geochemical maps are pictorial representations of geochemical data. If used with proper caution, these data can help: (1) observe correlations among elements, (2) identify broad geochemical trends, (2) determine regional background values for the elements present, and (4) select areas of interest for more detailed study (for example, see Webb and others, 1978; Earth and Space Sciences Division, Geochemistry Group, 1984).

Effective interpretation of the data presented in the atlas should include usage of every available piece of geologic information obtainable. Selected geochemical maps are displayed at 1:200,000-scale and should be used in conjunction with the topographic and geological maps published at the same scale, with the basic statistics, mineral deposit model information (USGS and others, 1987), and geochemical data and overlays included with this report.

Interpretation of geochemical data is sometimes subjective and care must be used in evaluation. One method commonly used is to select areas that contain anomalies (Levinson, 1980). An anomaly is a geochemical concentration usually much higher than normal or expected background levels.

Geochemical anomalies may be due to several factors: (1) the anomaly may be an indication of an ore deposit, (2) it may result from sub-economic concentrations of the indicated elements, (3) it may be caused by analytical or sampling errors, (4) the anomaly may be due to contamination by human activities, or (5) the anomaly may be a natural variation due to geology, vegetation, or stream geometry.

Detailed follow-up surveys in areas of interest can determine if factors 1, 2, or 5 are true (for example, see Boyle, 1979). The use of standardized field and analytical procedures reduces the likelihood of anomalies due solely to factor 3. Factors 4 and 5 require careful integration of all available data.

Contamination due to human activities (factor 4 above) may be unavoidable, but is often obvious upon examination of the data. For example, sample #5168-2169 was collected from the Rio Torres just below the confluence with the Rio Tiribi. This sample represents drainage from the metropolitan San Jose area and has a very high concentration of nearly every metal analyzed (chromium, cobalt, gold, iron, lead, mercury, silver, titanium, vanadium, and zinc). These concentrations are likely the result of contamination from urban activity.

Contamination from existing and abandoned mining activities is also usually apparent. For example, the Rio Machuca contains high concentrations of gold, arsenic, and antimony along its entire course, probably as a result of mining activity upstream. The gold, arsenic, and antimony anomalies are highest in the catchment basin where the mining activity occurs, and elemental concentrations decrease downstream. The high concentration of gold (up to 0.55 ppm) and silver (up to 11 ppm) may be an indication that the benefication processes being used need improvement. In addition, concentrations of arsenic in these stream sediments (up to 3175 ppm) may indicate the waters in areas of current mining activity could be a health hazard if regularly used for consumption.

The elements presented in the Atlas may be used singly or in groups to provide information for locating areas most desirable for future investigation. Concentration of a single element rarely occurs in nature; however, the relatively high concentrations of chromium in the southwest portion of the San Jose quadrangle is indicative of the mafic nature of the ocean floor basalts of the Nicoya complex, and this single element thus is useful in identifying this type of geology. A more common situation is that suites of elements typify particular rock types and/or ore deposits. These elements tend to be associated because of similar geochemical behavior during geologic processes. Elements that can be used as guides to various types of mineralization are referred to as pathfinder elements.

A pathfinder element may be the element of economic interest being sought (for example, copper in a porphyry copper system) or the pathfinder may be an element with no economic value, but which substitutes in the structure of the ore mineral itself, or occurs in the gangue. For example, arsenic can be a pathfinder for vein-type gold deposits. The most useful pathfinder elements are those which are generally more abundant, more mobile, and more easily detected than the element being sought. An area containing a gold anomaly plus a favorable suite of pathfinder elements may be considered more favorable for gold mineralization than an area with gold and no pathfinders. Rose and others (1979) and Levinson (1980) provide further information regarding the use of pathfinders.

Results

The geochemical maps for the elements gold, arsenic, and antimony indicate that gold mineralization may be found southeast of the presently known limits of the gold district in the Tilaran-Montes del Aguacate Range. Arsenic and antimony are excellent pathfinders for many types of gold deposits in Costa Rica (Arauz, 1986; USGS and others, 1987). The average contents of arsenic and antimony in igneous rocks are 1.5 and 0.2 ppm, respectively. Samples taken from drainages of active gold mines in the San Jose quadrangle contain arsenic concentrations greater than 3000 ppm and antimony concentrations greater than 90 ppm. This southeasterly extension follows the trend of the Tertiary volcanic units (Tv on the bedrock map overlay), the host rock of the known gold deposits (USGS and others, 1987). An attractive target for follow-up studies here would be drainage basins containing high concentrations of gold, arsenic, and antimony. Silver, copper, and lead also have increased or high concentrations in samples near active mines, but the increase is much less pronounced than with arsenic and antimony.

Another area that may have potential for gold mineralization lies just north of Ciudad Quesada on the flanks of Volcan Platanar. If mineralization exists in this area, the geology and geochemistry are suggestive of hot-spring-type deposits (see model descriptions in USGS and others, 1987).

There is no obvious indication for new gold mineralization in the Golfito quadrangle, even though gold placers are known (Castro and Vargas, 1982; USGS and others, 1987). Subtleties in the data, which would more clearly identify Golfito gold placers, may only become apparent by the use of more advanced statistical techniques (see examples in Davis, 1986).

These are only a few examples of the more obvious areas that warrant follow-up work. Continued use and examination of the Atlas will undoubtedly reveal other such areas. For example, the effects of mining activities and geology may geochemically mask areas with potential for mineralization. These effects can be statistically removed,and could enhance anomalies. Field work should be directed towards confirming or eliminating areas identified as having potential mineralization. The regional geochemical data in the Atlas, combined with the USGS studies (USGS and others, 1987), provide the foundation for determining the future of the minerals industry of Costa Rica.

DISCUSSION

Our initial analysis for the elements U and Th in the 1970s has evolved into the analysis of a multielement suite. The resulting increased data provide tremendous amounts of information for a variety of fields in addition to exploration. These include, but are not limited to, studies in general geology, agriculture, human and animal health, and investigations of the environment. Today about 45 elements are routinely analyzed by instrumental neutron activation analysis at Los Alamos. Additional elements are analyzed by other techniques on an as needed basis. The multielement suite allows a new dimension in routine examination of data. Elemental ratios, analyses for the rare earth elements, and other elements not commonly examined in the 1970s, are now routinely provided.

The end products for most regional geochemical surveys are geochemical maps. Our initial programs provided voluminous data listings, and black and white geochemical overlays. Symbol size on these maps related to elemental concentrations. Current technology allows for publication of color-coded geochemical maps at any desired scale. Once the required hardware is purchased, working copies of maps are produced for literally pennies per map; this is a cost savings of 10-100x earlier production costs. Raw data are now made available on microfiche or in digital format on magnetic medium, reducing the need for hard copy listings.

Some of the most notable changes in exploration geochemistry are the improvements in data manipulation and integration software. Many of our early programs required a simple physical examination of the geochemical maps. This examination was usually accompanied by basic statistics (mean, standard deviation). This technique has evolved into utilizing integrated data systems that contain a variety of geological, geophysical and mineral deposit information. Complex statistical programs, such as factor analysis, can be incorporated into routine examinations of regional data.

Many organizations that had regional surveys conducted ten years ago simply required the data and geochemical maps as the end product. Today, not only are the data requested, but transfer of hardware, software and data evaluation techniques are also commonly requested. Users of regional stream sediment geochemical data are becoming as interested in the processes utilized in displaying the data as in the interpretation of the data.

Methods of sample collection have also changed in the past few years. Samplers once had to carry 2 kg of sample from each sample site. Now only about 50 g of sample is collected. This is especially important where sample sites are in rugged, remote regions.

To summarize, changes in methodology and technology in the last several years have resulted in more efficient sample collection, analysis, and map generation techniques for regional stream sediment geochemical surveys. Organizations that use regional geochemical data are often as interested in technology transfer as in evaluations of the data.

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